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DOI: https://doi.org/10.1519/JSC.0000000000002539

Journal of Strength and Conditioning Research Publish Ahead of Print
DOI: 10.1519/JSC.0000000000002539

Performance in 100-km ultra-marathoners – At which age it reaches its peak?

Running head: Age of peak performance in 100-km running

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Abstract

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Key words: master athlete; women; men; ultra-endurance

INTRODUCTION

The 100-km running race is an ultra-endurance sport of increasing popularity (2). Every endurance sport has its unique age of peak performance depending on its distance or duration (1). The knowledge of this specific age is important for athletes and coaches to specifically prepare for a certain race distance in order to achieve the best performance in life.

The age of peak performance has been previously studied in running events such as marathon and ultra-marathon. Previous studies on marathon (7, 10, 12-14, 18) used different samples (e.g. top athletes, all finishers) and different methods (e.g. multiple linear regression models, non-linear regression analyses, mixed-effects regression analyses).

Depending on the methodological approaches of the abovementioned studies such as analysis and finishers' characteristics (e.g. nationality, performance level), the peak performance was found at ~25-35 years (10, 12-14, 18). For instance, the fastest and the youngest marathoners originate from East Africa with Ethiopian runners being the fastest marathoners worldwide (14) and achieving their fastest marathon race time at an age of ~26 years, whereas Kenyan runners were the second fastest and achieved their best times at an age of ~30 years (10).

In ultra-marathon running, the age of peak performance has been examined in several distances such as 100-km ultra-marathon (2), 100-miles (161 km) ultra-marathons (17) and races held in hours (i.e. 6 hours, 12 hours, 24 hours, 48 hours, and 72 hours)

and days (i.e. 6 days and 10 days) (11). Compared to the marathon, the peak performance has been observed in ultra-marathon at an older age (i.e. ~35 years or older).

Particularly, in 100-km ultra-marathon running, the age of the fastest women and men runners remained unchanged at ~35 years across calendar years although the runners improved their performance over time when the annual ten fastest women and men 100-km ultra-marathoners between 1960 and 2012 were analyzed (2). A methodological limitation of previous studies in 100-km (2) and 100-miles (17) ultra-marathoners was that these investigated the age of peak running performance by limiting to the annual fastest (i.e. top ten) women and men. A further methodological issue was that Lehto (13) showed that a second-order (non-linear) polynomial with $y = a + bx + cx^2$ described the best the relationship between performance and age in marathoners, in a study where either examining the fastest or all finishers in 1-year age intervals resulted in assessing the age of peak performance at ~34 years. Similarly, Lara et al. (12) showed for elite marathoners that the relationship between age and running time was U-shaped where the lowest race time was obtained at 27 years in men and at 29 years in women. The differences between these ages might be due to the fact that Lehto (13) investigated recreational athletes while Lara et al. (12) analyzed elite marathoners.

We assume that the existing studies investigating the age of peak ultra-marathon running performance analyzing only the 10 fastest finishers were not able to correctly determine the age of peak running performance. Knowledge about the age of peak performance in 100-km ultra-marathoners has both practical and theoretical

implications. From a practical perspective, it will make it easier for strength and conditioning trainers working with these runners to set realistic long-term age-tailored goals for competition and training. From a theoretical perspective, it is expected to improve the understanding of exercise physiologists and gerontologists about the relationship between aging and human performance. Therefore, the aim of this study was to determine the age of peak performance in women and men 100-km ultra-marathoners by using a second-order non-linear regression analysis following Lehto (13). Secondary aims were to examine trends in participation, performance and age of finishers across calendar years.

METHODS

Experimental Approach to the Problem

All finishers in a 100-km ultra-marathon held worldwide between 1959 and 2016 were analysed. All data were downloaded from the website of DUV (Deutsche Ultramarathon Vereinigung; http://statistik.d-u-v.org/) and were examined for duplicate cases and extreme scores prior to further analysis.

Procedures

All procedures used in the study were approved by the Institutional Review Board of Kanton St. Gallen, Switzerland with a waiver of the requirement for informed consent of the participants given the fact that the study involved the analysis of publicly available data. The study was conducted in accordance with recognised ethical standards and national/international laws.

Subjects

Excluding duplicate cases (i.e. where runners were recorded in the open race and in the Championship race such as a European or a World Championship) and finishers' extreme scores (i.e. average running speed less than 2.5 km/h or more than 30 km/h) resulted in a final consideration of 370,051 finishers (i.e. 44,601 women and 325,450 men). The distribution of finishers by sex, 5-year age group and calendar year can be seen in the **Supplement**.

Statistical analyses

The alpha level was set at a=0.05. Descriptive statistics (mean±standard deviation) were used to present all data. All statistical analyses were performed using GraphPad Prism v. 7.0 (GraphPad Software, San Diego, USA) and IBM SPSS v.23.0 (SPSS, Chicago, USA). The men-to-women ratio (i.e. the quotient of the number of men by women finishers) was used to study the sex differences in participation for the whole sample and each age group. To address the question whether the men-to-women ratio varied by age groups, chi-square (χ^2) examined the association of sex and age group, and Cramer's phi (φ_C) evaluated the magnitude of this association. Moreover, the association of sex and calendar year was examined, i.e. whether the men-to-women ratio varied by calendar year. Two methodological approaches were used to examine the effect of age on performance; the finishers were categorized either into 5-year groups from <20 to >84 years or 1-year groups from 15 to 80 years. Each approach provides different information; for instance, 1-year groups might have more theoretical interest as they provide detailed analysis about the effect of age, whereas 5-year groups might have more practical implications as they correspond to the official classification of marathon runners.

Moreover, we analyzed both all and the top ten finishers in each approach, since strength and conditioning professionals working with elite ultra-marathoners might be more interested in the trends for top ten finishers, whereas those working with recreational ultra-marathoners might be interested in the trends for all finishers. A two-way ANOVA examined the main effects of sex, age group and calendar year, and the sex × age group and sex × calendar year interaction on race speed. Bonferroni post-hoc analysis was used to identify differences among age groups or calendar years. The magnitude of differences in the ANOVA was evaluated using eta-squared (η^2) as trivial ($\eta^2<0.01$), small ($0.01\leq\eta^2<0.06$), moderate ($0.06\leq\eta^2<0.14$) and large ($\eta^2\geq0.14$) (3). We ran the ANOVA for all and top ten finishers separately. The age of peak performance was estimated using a non-linear regression model with a second order (i.e. quadratic) polynomial function ($y=ax^2+bx+c$). The vertex of the quadratic function was calculated as $p(x|y) = (-\frac{b}{2a} \mid C - \frac{b^2}{4a})$. We determined the age with the peak performance for both all and top ten finishers in 1-year and 5-year age intervals.

RESULTS

Running speed of all and top ten finishers by sex

For all finishers, we observed a small main effect of sex on running speed ($p<0.001$, $\eta^2=0.011$), where men were faster by +7.5% than women (8.35±2.26 km/h versus 7.77±1.91 km/h, respectively). For the top ten finishers, we found a medium main effect of sex on running speed ($p<0.001$, $\eta^2=0.116$), where men were faster by +16.6% than women (14.29±2.82 km/h versus 12.25±2.89 km/h, respectively).

Running speed of all finishers across years

Considering the trend in running speed across calendar years, we found a small main effect of calendar year on running speed ($p<0.001$, $\eta^2=0.042$), with the slowest running speed in 1960 and the fastest running speed in 1995 (**Figure 1**). Running speed increased from 4.75±0.33 km/h (1962) to 6.87±1.76 km/h (2016) in women and from 5.61±0.74 km/h (1959) to 7.29±1.83 km/h (2016) in men. There was a trivial sex×calendar year interaction on running speed ($p<0.001$, $\eta^2=0.001$), where the sex difference decreased across calendar years.

*** Please, insert Figure 1 near here ***

Finishers by 5-year age group

Most finishers were recorded in age group 40-44 years for men, but in age group 45-49 years for women (**Figure 2**). The total men-to-women ratio was 4.13. There was a sex×race association of participation ($\chi^2=22906.483$, $p<0.001$, $\varphi=0.163$) with a men-to-women ratio of 7.30. A sex×age group association was found ($\chi^2=1098.043$, $p<0.001$, $\varphi=0.058$) with the smallest men-to-women ratio in the 45-49 age group (6.53) and the largest in the 80-84 age group (32.60). A sex×calendar year association was observed ($\chi^2=5011.898$, $p<0.001$, $\varphi=0.124$)

*** Please, insert Figure 2 near here ***

Running speed in all and top ten finishers by 5-year age group

When all finishers were considered in 5-year age groups, a small main effect of age group on running speed was observed ($p<0.001$, $\eta^2=0.010$) (**Figure 3**). In addition, a

177 trivial sex×age group interaction on running speed was shown ($p<0.001$, $\eta^2=0.001$).
178 When the top ten finishers by 5-year age groups were considered, a large main effect
179 of age group on running speed was found ($p<0.001$, $\eta^2=0.939$) (**Figure 4**). Moreover,
180 a large sex×age group interaction on running speed was observed ($p<0.001$,
181 $\eta^2=0.361$). That is, the main effect of age group and the sex×age group interaction on
182 running speed had larger magnitude when the top ten finishers were considered
183 compared to all finishers.
184
185 *** Please, insert Figure 3 near here ***
186 *** Please, insert Figure 4 near here ***
187
188 **Running speed in all and top ten finishers by 1-year age group**
189 When all finishers were considered in 1-year age intervals, a small main effect of age
190 group on running speed was observed ($p<0.001$, $\eta^2=0.010$) (**Figure 5**). In addition, a
191 trivial sex×age group interaction on running speed was shown ($p<0.001$, $\eta^2=0.001$).
192 When the top ten finishers by 1-year age group were considered, a large main effect
193 of age group on running speed was found ($p<0.001$, $\eta^2=0.909$) (**Figure 6**).
194 Furthermore, a large sex×age group interaction on running speed was observed
195 ($p<0.001$, $\eta^2=0.226$). The main effect of age group and the sex×age group interaction
196 on running speed had larger magnitude when the top ten finishers were considered
197 compared to all finishers, as has been found in the analysis using 5-year age groups.
198
199 *** Please, insert Figure 5 near here ***
200 *** Please, insert Figure 6 near here ***
201

Age of all finishers by sex and calendar year

Men (43.7±11.2 years) were younger than women (43.8±9.8 years) (p=0.027) (**Figure 7**). The age of finishers of both sexes increased through time (**Figure 8**). The age increased from 22.50±4.95 years in women (1962) and 36.13±9.81 years in men (1959) to 43.90±9.42 years in women and 44.84±9.98 years in men (2016).

*** Please, insert Figure 7 near here ***

*** Please, insert Figure 8 near here ***

The age of peak running speed of all and top ten finishers by 5- and 1-year age group

Considering all finishers in 5-year age groups, the age of peak running speed was 40-44 years in women and 45-49 years in men (**Table 1**). Considering the top ten finishers in 5-year age groups, the age of peak running speed was 30-34 years in women and 35-39 in men. Considering all finishers in 1-year age groups, the age of peak running speed was 41 years in women and 45 years in men (**Table 2**). Considering the top ten finishers in 1-year age groups, the age of peak running speed was 39 years in women and 41 years in men.

*** Please, insert Table 1 near here ***

*** Please, insert Table 2 near here ***

DISCUSSION

The aim of this study was to determine the age of peak running speed in women and men 100-km ultra-marathoners by using a second-order non-linear regression analysis. We found, depending upon whether all finishers or the top ten finishers in 1-

year or 5-year age groups were considered, differences in the age of peak running speed. When the top ten were considered in 5-year age groups, the fastest runners were at the age of ~35-39 years. When all finishers were considered, the age of peak running speed was at age groups 40-44 and 45-49 years. When all finishers were considered in 1-year age group intervals, the age of peak running speed was 41 years in women and 45 years in men. However, when the top ten finishers were analysed, the age of peak running speed was 39 years in women and 41 years in men.

Obviously, the age of peak running speed in 100-km ultra-marathons is (a) older than reported for marathon running and (b) older than in existing reports for 100-km ultra-marathoners. In existing reports, the age of the fastest 100-km ultra-marathoners was reported to be at ~35 years when the annual fastest women and men were analyzed (2). While that study used only the top athletes and regression analyses were performed, we investigated apart from the top athletes also the whole sample of athletes. Furthermore, we determined the age with the fastest race time considering age groups in 1-year and 5-year intervals using a non-linear regression model with a second order (i.e. quadratic) polynomial function.

Potential explanations for the older age in peak running speed in these 100-km ultra-marathoners than expected could be the trend across years since the age of the runners increased across calendar years. Most probably this increase of age in peak ultra-marathon performance is typical for this sports discipline. When runners competing in time-limited ultra-marathons held from 6 hours to 10 days during the 1975-2013 period were analyzed, the age of peak performance increased across calendar years (9). Also, the relatively older age of peak performance in 100km than in marathon

might be due to a later engagement of runners in ultra-endurance training and the older age of ultra-marathoners compared to marathoners. A comparative study between ultra-marathoners and marathoners showed that the former were older by 3 years than the later and had completed more marathon races (34 versus 12, respectively) (8). In turn, marathoners were older by 2.6 years and had more years of experience than half-marathoners (19). Furthermore, ultra-endurance athletes seemed to prepare differently for their races compared to endurance athletes where ultra-endurance athletes invested more time in training and completed more training kilometers at lower speed compared to endurance athletes (16).

However, an increase in the age of peak performance has also been reported for elite Ironman triathletes competing in 'Ironman Hawaii'. When the changes in the age and performances of the annual top ten women and men competing at the Ironman World Championship 'Ironman Hawaii' between 1983 and 2012 were analyzed, the age of annual top ten women and men triathletes increased over the last three decades while their performances improved (4). In the present 100-km ultra-marathoners we found the same trend where age increased and performance improved across calendar years although we analyzed all annual finishers without restriction to the annual top ten finishers.

A main observation regarding the findings of the present study was that these varied depending on the applied methodological approaches, i.e. whether all or top ten finishers were considered, or whether the finishers were classified in 1-year or 5-year age groups. It should be highlighted that all approaches are useful; however, they have certain advantages and disadvantages. For instance, considering the top ten finishers

278 results in well-fitted modelling of the relationship between performance and age
279 ($0.91 \leq R^2 \leq 0.96$, 5-year age, Table 1; $0.72 \leq R^2 \leq 0.84$, 1-year, Table 2), but the
280 modelling was weaker when all finishers are considered ($0.02 \leq R^2 \leq 0.04$, 5-year age,
281 Table 1; $0.02 \leq R^2 \leq 0.04$, 1-year, Table 2). The discrepancy between the two
282 methodological approaches indicates that considering the top runners by age group is
283 more appropriate to study the relationship between performance and age. An
284 explanation of the discrepancy between the two approaches (top ten versus all
285 finishers) is that performance in the top ten finishers is related to the limits of human
286 performance which are influenced by aging (15) as shown by the almost perfect
287 relationship between age and performance. On the other hand, performance of all
288 finishers reflects non-biological factors, such as the participation rates, as shown by
289 the trivial-to-small relationship between age and performance. Another example of
290 methodological approaches yielding different findings was the sex difference in
291 performance; it was 7.5% in all finishers, but 16.6% in the top ten finishers with the
292 later being closer to the sex difference in VO_{2max}.
293
294 Most probably these ages of peak performance have also to do with the distribution of
295 recorded athletes in age groups. Most finishers were in age group 40-44 years for
296 men, but in age group 45-49 years for women. These age groups seem to be the
297 groups with the highest participation due to different reasons. When demographic
298 characteristics of 161-km ultra-marathoners were investigated, mean age of 489
299 runners was 44.5 ± 9.8 years. Apart from this specific age, the runners were generally
300 men (80.2%), married (70.1%), and had bachelor's (43.6%) or graduate (37.2%)
301 degrees (6).
302

A further finding was that the age of peak performance was younger in women than in men. This finding is in contrast to Hoffman (5) in 161-km ultra-marathoners in a retrospective analysis of results from 1977 through 2008, where the main finding was that the fastest race times were achieved by athletes in age group 30-39 years in men and in age group 40-49 years in women. Most probably the actual finding might reflect the overall younger age of women compared to men.

With regards to the limitations of the present study, it should be highlighted that the age of peak performance varies by distance in ultra-marathons; thus, caution is needed when generalizing the findings in these 100-km ultra-marathons to other distances. On the other hand, strength of the study is the very large number of finishers that were analysed.

PRACTICAL APPLICATIONS

The age of peak running speed in 100-km ultra-marathoners is older than in existing reports when using non-linear regression analyses. Although the age of peak running speed is slightly younger in women compared to men, the best 100-km ultra-marathon performance is expected at the age of ~40-45 years, therefore ~10 years older than in existing reports. The knowledge of the age of peak performance is of great practical value for coaches and fitness trainers working with 100-km ultra-marathoners in order to set optimal long-term performance goals. The findings of the present study suggest that the age of peak performance in this sport is older than that of peak of biological parameters, such as maximal oxygen uptake (15), associated with ultra-endurance performance. Considering that older studies had shown a relatively younger age of peak performance, it is reasonable to support that performance in 100-km ultra-

marathon becomes less dependent on biological factors across years. Therefore, coaches and fitness trainers should set more competitive performance goals for a given middle age compared to the past.

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Table 1 Parameters in the second-order polynomial regression running speed (km/h) = $a + bx + cx^2$ using the race speed of all and top ten runners in 5-year age groups

Parameter	Women	Men
All finishers		
a (km/h)	6.370	5.753
b (km/h/year)	0.505	0.763
c (km/h/year^2)	-0.044	-0.059
Age (years)	40-44	45-49
Running speed (km/h)	7.81	8.22
R^2	0.02	0.04
Top ten finishers		
a (km/h)	11.800	13.990
b (km/h/year)	0.867	0.710
c (km/h/year^2)	-0.090	-0.070
Age (years)	30-34	35-39
Running speed (km/h)	13.89	15.78
R^2	0.91	0.96

Table 2 Parameters in the second-order polynomial regression running speed (km/h) = $a + bx + cx^2$ using the race speed of all and top ten runners in 1-year age groups

Parameter	Women	Men
All finishers		
a (km/h)	4.715	3.329
b (km/h/year)	0.153	0.222
c (km/h/year^2)	-0.002	-0.002
Age (years)	41	45
Running speed (km/h)	7.82	8.23
R^2	0.02	0.04
Top ten finishers		
a (km/h)	5.660	7.823
b (km/h/year)	0.393	0.363
c (km/h/year^2)	-0.005	-0.004
Age (years)	39	41
Running speed (km/h)	13.30	15.28
R^2	0.83	0.72

List of figures

Figure 1

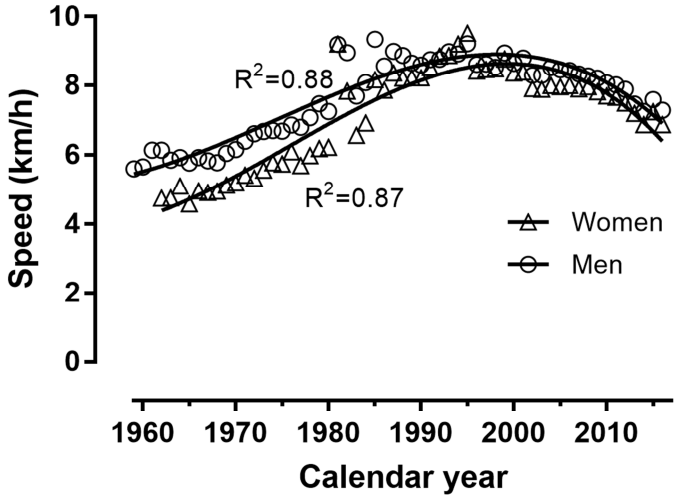

Figure 2

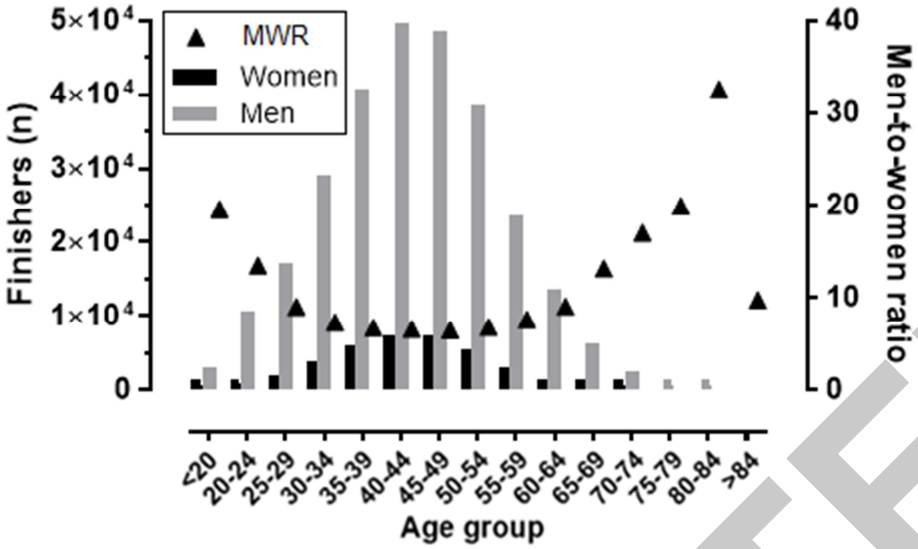

Figure 3

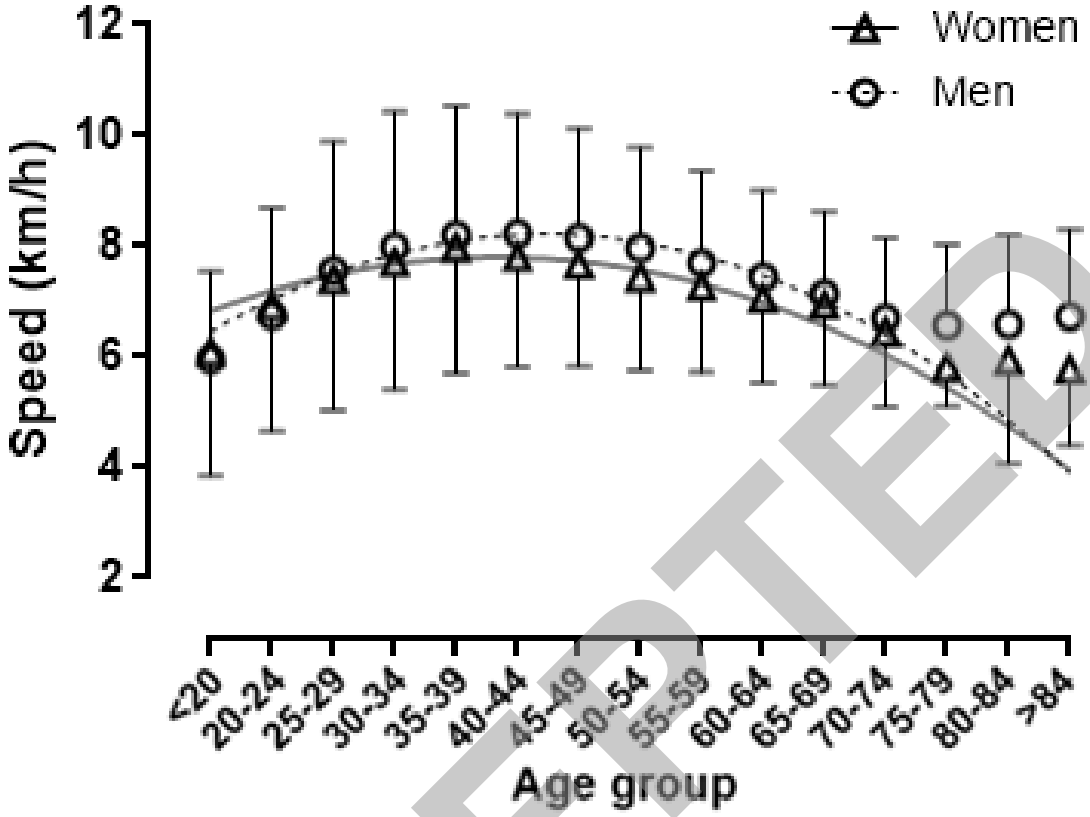

Figure 4

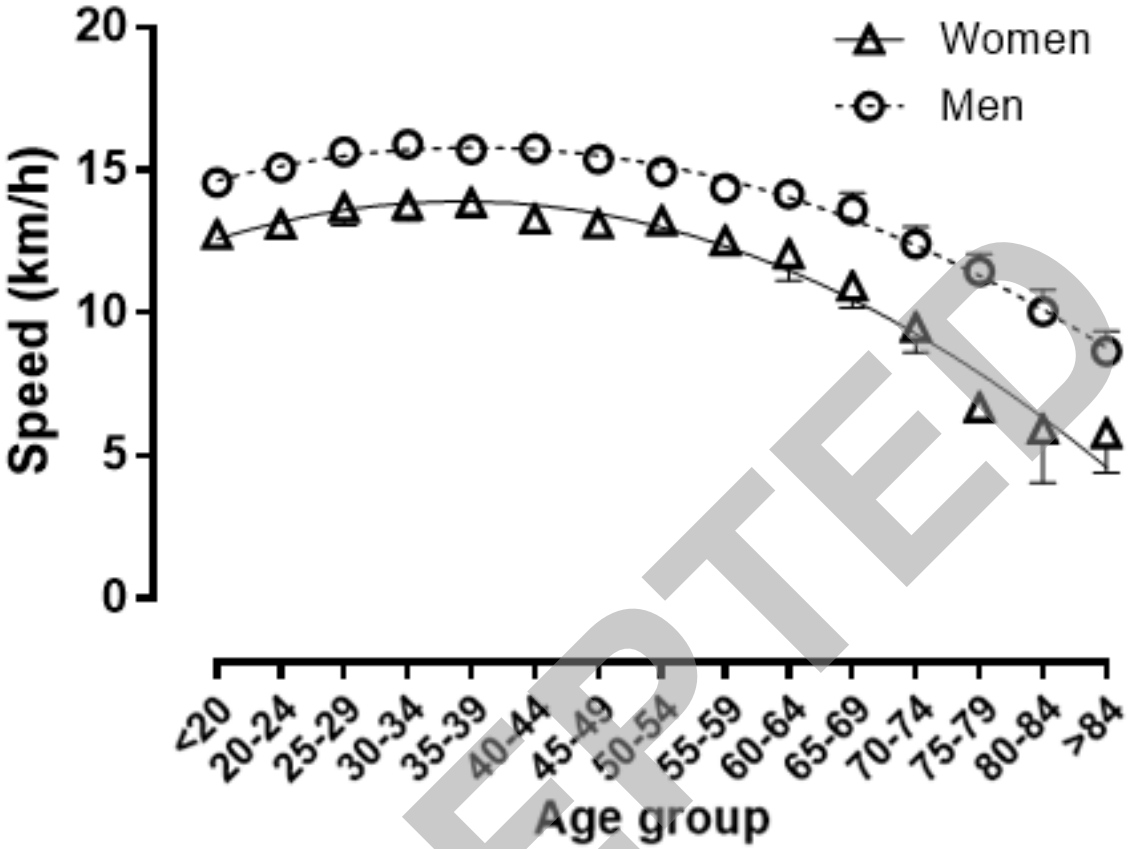

Figure 5

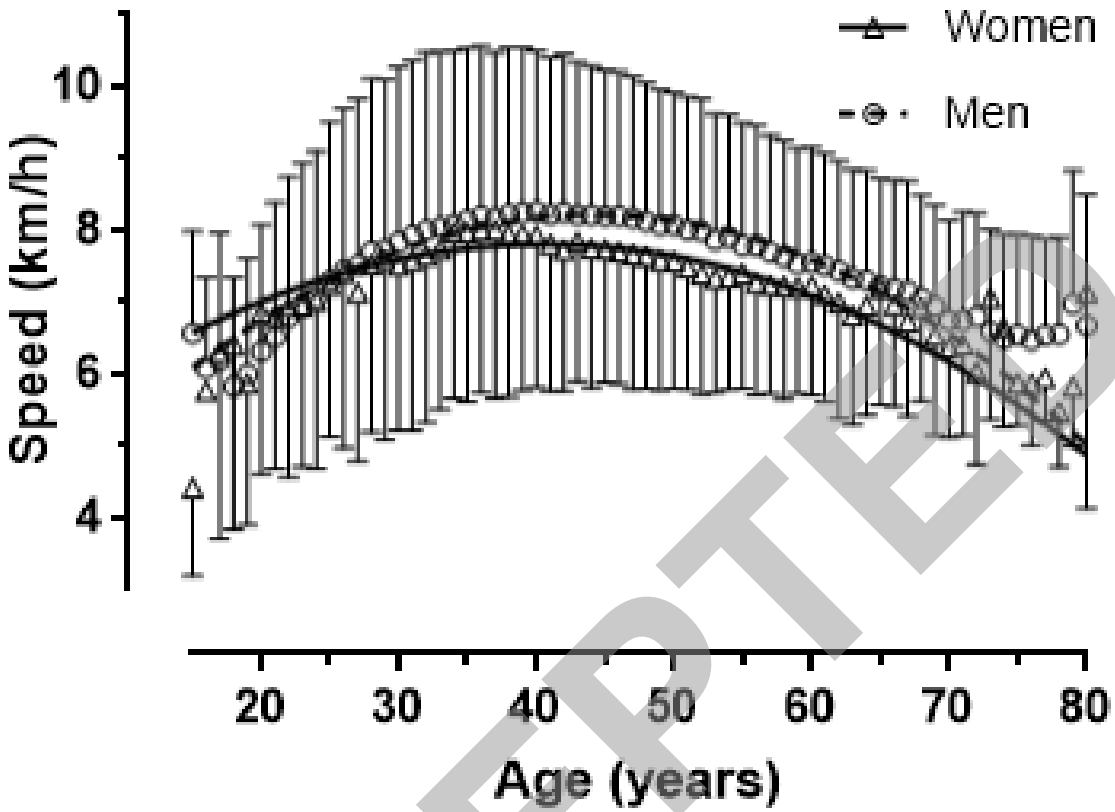

Figure 6

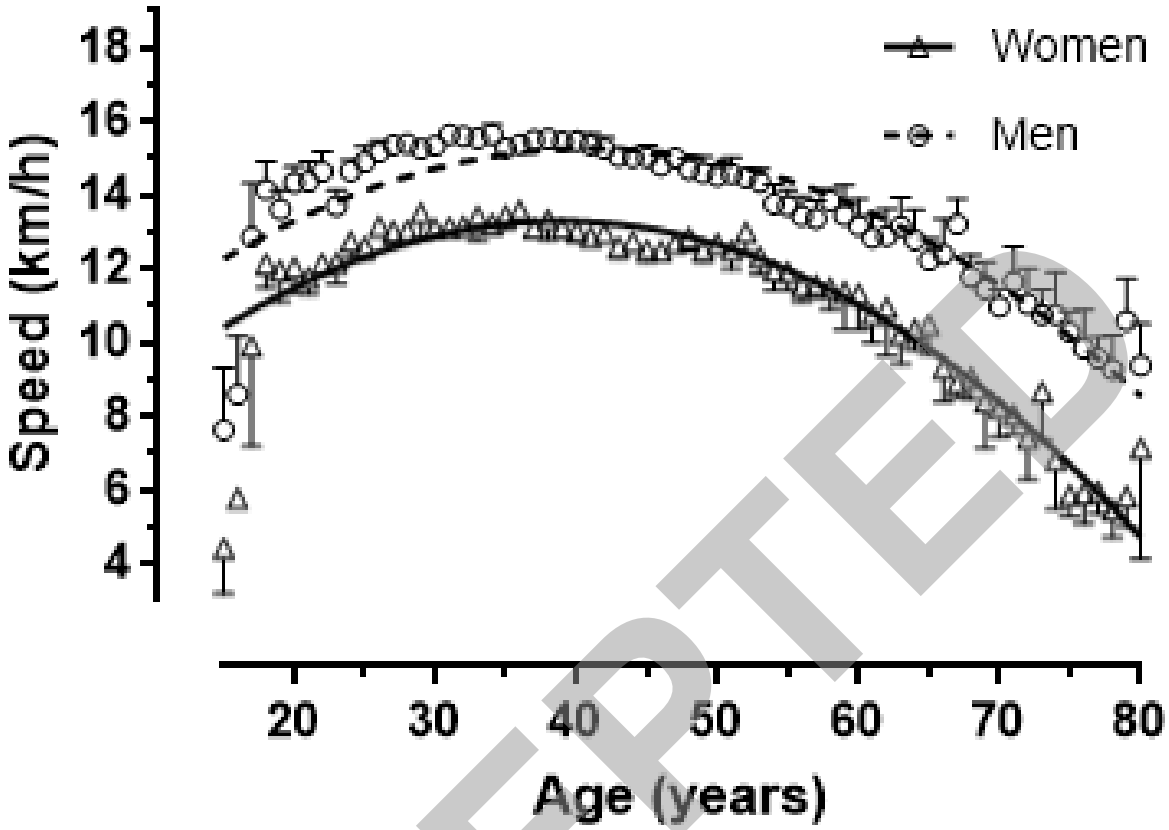

Figure 7

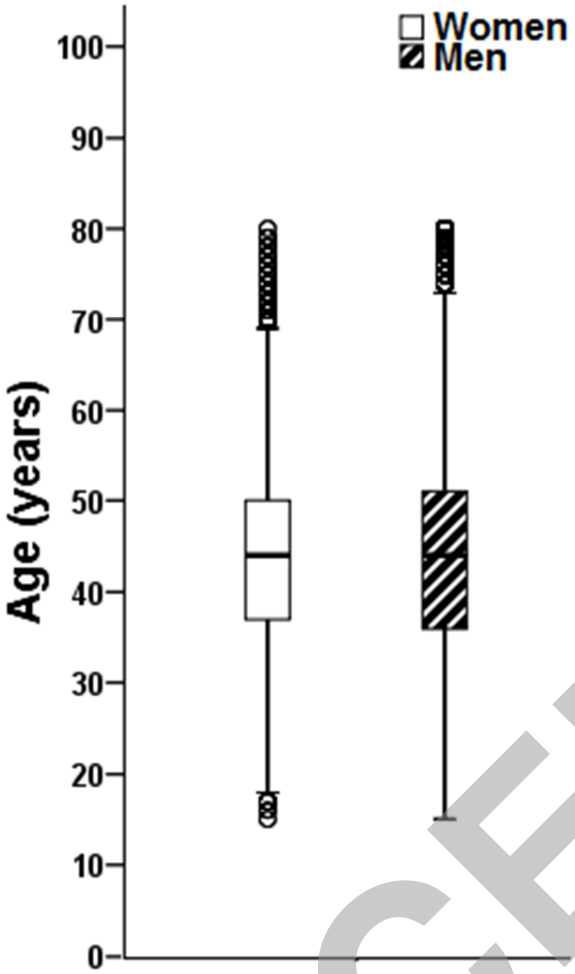

Figure 8